ECONOMIC CONSIDERATIONS OF DAMAGE ASSESSMENT

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Abstract: Cost-effectiveness is the fundamental economic test of any damage control or damage mitigation strategy, and damage assessment is the essential component for determination of cost-effectiveness. However, there are many potential costs associated with making damage assessments. The sampling and measurement required to produce a damage assessment have associated effort and costs, but even greater costs can be incurred due to inappropriate management decisions resulting from inaccurate damage assessments. Other costs can result from using an assessment method that is unsuited to management objectives, or by misinterpreting or not understanding the relationship between observed damage and actual losses. The concepts of sampling, measuring and estimating damage for producing relevant inferences and management decisions are examined with the aid of a variety of examples and simulations.

Key words: cost-efficiency, damage control, damage estimate, damage index, losses, management objectives, sampling

Cost-effectiveness is the ultimate test of any damage reduction strategy, because damage control practices represent a cost to agriculture industries that must be balanced by a benefit to production (Salmon and Lickliter 1983, Caughley and Sinclair 1994). Historically, damage control has involved identifying the species perceived to be causing damage and removing it. Accordingly, success was measured by the level of population reduction. In contrast to this view, it is more generally recognized now that control programs should be developed with the objective of minimizing damage (Fiedler and Fall 1994). Thus, damage assessment would seem to be among the foremost objectives when addressing human-wildlife conflicts, although this often is not the case (e.g., Hone 1995). A broad array of costs potentially can arise in the process of assessing damage, but the deprivation of information from not evaluating damage could be the most costly approach to a damage situation. The most obvious costs involved in carrying out damage assessments are the direct costs of materials, manpower and any crop destruction needed to produce the assessment. However, there are a number of other potentially more substantial costs that can arise when considering the assessment's impact on management decisions and their timing, and how those decisions impact the economics of loss.

OBJECTIVE-BASED DAMAGE ASSESSMENT

Assessment of animal damage is integral for a variety of management objectives aimed at minimizing losses (Table 1). The sampling frame, measurements, and estimation procedures used to conduct a damage assessment should be compatible with the specific management objective. A review of the primary objectives for conducting damage assessments provides a background for understanding the sources and magnitudes of the potential costs associated with damage assessment.

First, damage levels can be monitored as part of the management decision process that determines whether damage reduction methods are warranted, what method(s) to implement, and/or the timing for implementation. A second objective for carrying out damage assessment is to evaluate the efficacy of the damage control measures, usually by comparing pre- and post-control damage levels, or by comparing treated and untreated sites. Related to this, damage assessments are used in some situations to determine the claim amounts to a government agency in compensation for losses to "publicly-owned" animals. Another objective is the use of damage assessments, taken in a consistent manner over time and locations, to provide a historical record from which predictive relationships can be generated for relating environmental and cultural factors to potential damage levels. Damage also can be assessed according to incidence or pattern to better define the breadth of the problem on a range of geographic scales, and to optimally target mitigation procedures. Lastly, for some species and habitats, damage levels form a useful index for monitoring population abundance (divergent from the purposes of this paper).

Table 1. Summary of the most commonly applied objectives for carrying out damage assessments.

Criteria for decision process about implementing damage control procedures
Is control warranted?
Methods to implement based on projected cost-efficacy
Timing of control implementation
Evaluate damage control efficacy
Pre- versus post-control comparisons
Comparison of controlled to uncontrolled areas
Damage compensation claims
Predictive record for damage
Index animal abundance

EFFORT AND RESOURCES TO QUANTITATIVELY DESCRIBE DAMAGE

A quantified description of damage should conform to the requirements of management objectives. The effort and resources applied to meet the damage assessment objective are dictated by the sampling method and the allocation of effort among sampling layers, the damage measurement method(s), and the calculation requirements of the quantitative damage descriptor(s). Clearly these 3 factors are not independent and serve to constrain each other. Inattention to any 1 of them could result in an unnecessarily costly assessment, or even render the assessment effort (and expenditure) of no value. The influences of these factors on the costs of carrying out a damage assessment are considered separately here.

Sampling Damage

The scale at which inferences are to be made determines much of the sampling scheme and how study resources are to be allocated. Sampling and resource allocation would differ for inferences to be made about 1 field versus inferences about a farm, a region, or a nation. Decisions on control strategies will vary according to scale of observed damage. For example, average damage throughout a region could be inconsequential, implying no need for a large-scale, coordinated damage control effort. On the other hand, an individual farm within that region could be hit hard, with the landowner or manager needing to identify the most cost-effective mitigation for the problem.

As the area to which inferences are to be applied increases, so does the number of layers of sampling. The sampling effort required to produce accurate estimates is balanced by the labor and logistics required to acquire the samples. Optimal allocation of resources/effort among the levels of sampling, is based on such factors as the cost of sampling at different levels, the logistics of sampling, and the variability contributed by each level of sampling (e.g., within field variability versus field-to-field variability, versus farm-to-farm variability, etc.). Errors or bias in a sampling method are propagated through all higher levels of sampling thus maximizing the distortion at the larger scale of inference.

Consider as an example the estimation of the yearly damage caused by wading birds in trout rearing facilities presented by Glahn (1997).

average # birds seen/hr (A)
x bird feeding rate fish/hr (B)
x hrs birds present/day (C)
x days birds present/yr (D) =
Yearly fish loss to wading birds (ABCD)

Of the layers of sampling represented here, the 1 exhibiting the greatest variability generally should be sampled most heavily to minimize the influence that an extreme observation can have on the product, ABCD. Consider what would happen if, through human nature, birds seen to be feeding most heavily were more likely to be included in sampling. Say this produced an average sampling bias of only 10%. Thus, B in the above equation would be recorded as 1.1*B. While a 10% increase in B might not appear as much, the product ABCD could be a much larger number, and it too would be increased by 10%, resulting in a much greater economic assessment of loss than reality. This in turn could trigger greater expenses in mitigation procedures than would otherwise be necessary.

Measuring Damage

The measurement should efficiently address the assessment objective, otherwise the objective will not be met, or the objective may be addressed, but at a greater labor and resource cost than necessary. Examples in the following subsections also serve to illuminate this latter point, so the example that follows focuses entirely on the bias potential for measurements. A flaw or bias in the measurement method nullifies the most elegant of sampling schemes.

Cranberry production is estimated to reflect losses to deer damage. Rather than creating a significant amount of damage through berry removal, deer damage the cranberry vines primarily during winter, which later reduces production at harvest. Consider the simulated cranberry example in Fig. 1, where the dark circles represent cranberries and the square represents a hypothetical 1' x 1' sampling plot. While a 1' x 1' sampling plot would normally contain 60-130 berries, the sparse berry distribution in Fig. 1 will more clearly illustrate sampling concepts without loss of generality. For the sake of reality in subsequent calculations, each of the berries simulated in Fig. 1 is considered to represent 10 field situation berries. The berries have been simulated at random, and this plot-worth of berries represents 1 sample point used in estimation of production. Let’s consider how to treat the berries intersecting the plot perimeter for measuring production. They are part in and part out of the square’s interior. If only the berries inside the square are included, then 7 berries in Fig. 1 are measured (i.e., weighed) from this plot. If all berries inside or touching the square perimeter are included, then 12 berries are measured. The first case probably underrepresents production while the second case probably overrepresents production. Assuming a random spatial pattern of berries, the berries intersecting the plot perimeter would be half in and half out of the square on average. Thus, a more representative count for the square would be 9.5 berries (in practice, it would be most efficient to designate two sides of the

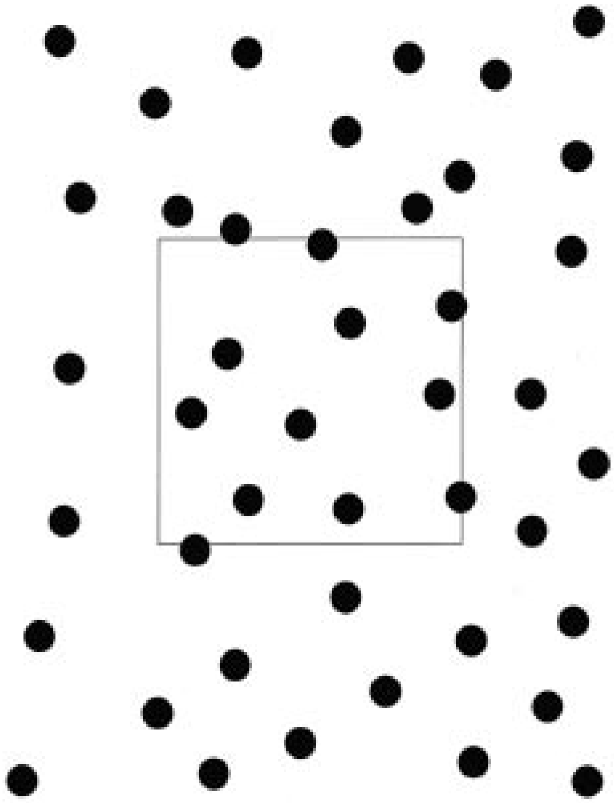

Fig. 1. A hypothetical square sampling plot (1' x 1') placed over randomly distributed simulated cranberries. For a realistic field situation, each simulated berry would represent approximately 10 cranberries.

square for which the berries would be included in the sample).

Now, let's consider how these discrepancies in measurements from the sampling square would affect economic estimates from a typical cranberry bed. First, let's presume that the numbers for the 3 types of measurements from the plot in Fig. 1 represent averages over multiple plots from the bed, and let's say each berry from Fig. 1 would realistically represent 10 berries from a field situation. Thus, our averages for the 3 types of measurements become 70, 120, and 95 berries. Typically, there are approximately 200 berries/lb, so the 3 values convert to an average of 5.6, 9.6, and 7.6 oz of berries measured in sampling plots for the bed. This converts to 152.5, 261.4, and 206.9 barrels of cranberries/ac, respectively for the different measurements from the same sampling square (Wisconsin Department of Natural Resources 1998). The typical cranberry bed is around 5 ac and cranberries are a high-value crop with the price per barrel recently fetching US$45-50 for juice and twice that for sale as berries. Thus, beginning with 3 possible measures for cranberries within a same-sized sampling plot, depending on treatment of the berries intersecting the perimeter of the sampling square, economic productivity for sale as berries from a typical bed could have been US$76,240, US$130,700, or US$103,470, a considerable economic discrepancy. (S. Beckerman, personal communication).

The next question is how this affects damage assessment inferences. Clearly for square areas such as the cranberry sampling plots, the ratio of the area of the plot to its perimeter length increases proportionally with the increase in side length. Thus, increasing the plots size would diminish the effect from berries intersecting the perimeter. Given that a 1' x 1' square plot typically holds 60-130 berries, increasing its size to make the perimeter effect negligible is impractical as it would represent too much labor in the field to be confident of reliable measurements. But if the same measurement method is used in damaged and undamaged areas, won't their difference still yield the same economic estimate of damage?

Assume that the example above was for an undamaged cranberry bed. Now assume that a damaged bed is sampled and produces exactly half the berries as the undamaged bed. And to make calculations straightforward, assume damaged and undamaged beds cover equal areas. The 3 different measurements then result in 3 different estimates of economic losses to damage: US$38,120, US$65,350, US$51,735. This example clearly reinforces the concept that substantial costs can arise if the most appropriate measurement is not used for damage assessment. As a relative economic index the selected measurement method of the 3 above may not have an impact, but consider the potential economic burden to the public or grower if these values determine compensation for losses.

Quantitative Descriptor of Damage

The stringency of the requirements for a quantitative descriptor of damage depends on the objective for the damage assessment. Typically, highly accurate estimation procedures require the greatest labor and resources to produce. Alternatively, more labor-efficient estimation may be available, but there may be some quantitative strings attached, usually in the form of caveats regarding robustness of inferences. For example, quadrat sampling is robust over spatial patterns (given an appropriate quadrat size), but can be labor intensive, especially when observations are sparse, unevenly distributed, or otherwise difficult to acquire (e.g., Engeman et al. 1994). Distance sampling methods were developed to reduce labor in the field, but many methods were developed assuming a random spatial distribution for the sampled population (e.g., Pollard 1971). This distributional assumption promotes the development of theory, but many, if not most, animal damage situations tend to occur in clumps or aggregations. Research has been conducted to develop and/or identify distance methods that provide satisfactory accuracy that is robust to different spatial patterns (Engeman et al.

1994), and variable area transect sampling (Parker 1979) has been optimized to produce high quality estimates (Engeman and Sugihara 1998). Optimized variable area transect sampling is an example of how labor-saving methods can be developed, and trials are underway in two states for testing this method for estimating deer damage to crops (currently, corn and cabbage).

For some damage assessment objectives, an easier-to-obtain index of damage can replace a more exact estimate of damage to formulate management decisions. As with damage estimates, indices result in quantitative information being collected and synthesized into a format from which inferences can be made. The index value should be sensitive to relative changes or differences in damage levels. Thus, in contrast to damage estimation where there is a premium on accuracy, precision is of the utmost importance for an index (e.g., Caughley and Sinclair 1994). For the most robust management inferences, the calculated index and associated variance should be burdened with as few assumptions as possible about the data structure and distribution of the observations. The reduced labor and resources required to produce an index value will only result in an economic savings if it satisfies the objectives of the damage assessment. Consider a method that has long been applied for assessing bird damage to grapes (Stevenson and Virgo 1971, DeHaven 1974, DeHaven and Hothem 1979). Indices are calculated from visual estimates for which percent-damage category best describes each observed grape cluster. The percent-damage categories are of unequal sizes; e.g., 0-5, 5-20, 20-50, 50-80, 80-95, 95-100%. Different authors have used different calculation nuances, such as category midpoints and transformations, for producing indices of damage from these visual estimates. An index calculated from these data can provide useful information on relative damage levels or trends that can be helpful for understanding relative damage levels among areas or through time, and assist in decisions on mitigation procedures. However, an accurate estimate of damage level is not possible from these observations, and if that is the damage assessment objective, other procedures should be considered, even if increased assessment expenses result.

UNDERSTANDING THE SYSTEM

When examining damage, what you see is not always what you get. Observed damage does not always equate to losses. Without a full understanding of the system and how damage relates to net product losses, control might be misapplied or mistimed. This concept is best illustrated by examples that demonstrate that the existence of damage does not necessarily imply an impact on production, and damage for 1 situation may not be damage in a similar situation. Further, a historical perspective on the environmental and population factors relating to damage may be necessary in some situations where delay of control procedures until the appearance of economical damage results in minimal economic benefit from the control.

Example 1. – In Hawaiian macadamia orchards black rats *(Rattus rattus)* feed on macadamia nuts throughout nut development (e.g., Tobin et al. 1996). In a series of studies, Tobin et al. (1993, 1996, 1997) used nut yields as criteria for evaluating the effects of rat removal from the orchard, and the effect of damage at different stages of nut development. While removal of rats reduced damage rates, nut yield was the same as when rats were not removed and produced generally low levels of damage (Tobin et al. 1993). Likewise, simulated damage indicated that growers might be able to sustain as much as 30% damage during early stages of nut development without a detrimental effect on yield (Tobin et al. 1996, 1997), although high populations and damage at this level may signal future production problems as nuts approach harvest (the third example discusses timing of control relative to damage and potential losses). Thus, reacting to observed low rat abundance and/or some damage at early stages of nut development with a control program are not likely to have a cost-benefit to growers. Continued monitoring would be a cost-effective means to rapidly respond to changes that might portend economic damage.

Example 2. – Wading birds, particularly great blue herons *(Ardea herodias),* are significant agents of damage in trout rearing facilities in the northeastern United States (Glahn 1997, Glahn et al. 1999b). Wading birds also are routinely observed to feed in commercial channel catfish *(Ictalurus punctatus)* facilities in the southern United States, and a survey of farm managers indicated a large majority believed they were incurring ever-increasing losses, with the majority of growers employing harassment programs to mitigate those perceived losses (Glahn et al. 1999a). However, when examined closely, wading bird predation was found to be a reflection of circumstances that brought fish to the surface such as disease, low oxygen, or fish feeding methods (Glahn et al. 2000). Therefore, damage abatement methods for the wading birds were largely unnecessary, except perhaps while fish were being fed. However, if 1 casually observed what appeared to be damage, unnecessary costs for control might be applied when those same expenditures could have been applied to solving germane problems.

Example 3. – Now consider an example of a system where rodent outbreaks occur in an annual crop. Observed damage often is used to trigger a population control action to reduce damage. A simple simulation offered by Ramsey and Wilson (2000) demonstrates how an understanding of the system from a historical damage perspective allows optimal timing of control and avoids the potential for adding the costs for inefficient control to the costs from lost production due to

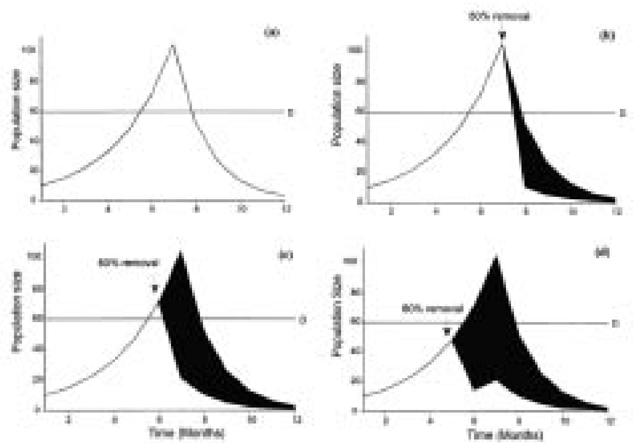

Fig. 2. Population trajectory of a hypothetical rodent population (a) without control procedures, (b) with 80% of the population removed at peak density, (c) with 80% of the population removed when damage is first observed and (d) with 80% of the population removed in anticipation of future damage. The horizontal line indicates a hypothetical level at which damage becomes substantial.

damage. Consider Fig. 2 where 80% of the damaging population is removed at various times through the harvest cycle. Observation of high damage levels may not always imply that damage control would be cost-effective. The high reproductive capacity and mobility of some rodent species makes it more efficient to prevent the problem from occurring than to commence control measures after damage has started (Ramsey and Wilson 2000). Harvest ends the potential for damage, and often reduces the population of damaging animals (Fig. 2a). Control initiated at peak population and peak damage rate may well be too close to harvest with substantial damage already accumulated, leaving little potential for the resulting damage reduction to equal control costs (Fig. 2b). Control initiated after damage had reached an economical level produced marginal savings in further damage (Fig. 2c). However, control initiated much earlier, before economical damage, would probably have required less effort and produced a lasting effect that maximized damage reduction (Fig. 2d). However, implementation of control procedures in anticipation of damage can only be cost-effective if there is reasonable assurance that populations will grow to proportions where the value of damage inflicted will exceed the control costs. Accurately being able to predict the situation where substantial damage is likely to occur requires monitoring damage, populations and environmental factors through time to identify the circumstances that lead to high damage.

In the first 2 examples, damage was clearly observed, but without an understanding of how the observed damage related to economic losses, the grower would likely be highly motivated to expend the resources necessary to implement damage control, but those efforts would have produced a negligible benefit over no control action. The last example demonstrates how understanding the system by integrating information sources, including damage assessment, allows control to be timed for maximum economic benefit.

DISCUSSION

The economic considerations for assessing animal damage is a very broad topic with a seemingly endless variety of problem situations. The need for clear, objective-based quantification has been considered in conjunction with the complexities of interactions of sampling, measurement, and calculation of damage descriptors. As some final thoughts for minimizing potential costs for conducting damage assessments, some cautionary comments are provided concerning the importance of the validity and practicality of the methods applied for damage assessment.

Method validity. – Prior to the application of a method to quantify animal damage, consideration should be given to its qualities for meeting management objectives and its suitability for use in a particular situation. A number of sampling and measurement methods may be available, from which the most appropriate method, or set of methods, must be selected. On the other hand, a tested method may not be available. A method used successfully on a similar damage situation would be a good candidate method to apply, but it should be validated to meet management needs. A new method for the species and damage situation should be applied concurrently with another proven (but perhaps more difficult) method, or otherwise validated on the target species before being used exclusively for making management or research inferences. Without such validation, assessment results and consequent management decisions are speculative. We saw an example of this with wading birds in aquaculture. Observed predation in trout-rearing facilities is a valid measure of damage that can be used to determine the most cost-effective control strategy. On the other hand, the same observation in catfish facilities is a reflection of environmental circumstances, rather than the birds' propensity for predation at the facilities. Similarly, variable area transect sampling may provide outstanding results in 1 field situation, but prove unsuited for another.

Method practicality. – For almost any damage situation, a sampling and measurement scheme can be conjured that, if carried out, would produce highly accurate damage estimates at whatever scale desired. However, an essential characteristic of a successful damage assessment procedure is that it is practical to apply. A procedure that is too difficult, too inefficient, or too expensive to apply will ultimately result in poor data and an inability to make lucid management decisions. Inefficient or uneconomical procedures usually will result in the collection of too little data from which to base management decisions. Related to this, the assessment method should be user-friendly, with the procedures and concepts for recording information easily understood. It should not require excessive manpower and the potential for observation bias should be minimal. The observer should be readily able to identify and measure the observation of interest, with little chance for confusion with damage from other sources such as weather or mechanical sources. Methods must impose minimal inconvenience on landowners and managers for them to be acceptable and implemented. All of these concepts are compounded in situations where the assessments must take place multiple times per year.

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